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Assigning firm-level GHGE reductions based on national goals - Mathematical model & empirical evidence

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ABSTRACT

The so-called Paris Agreement, signed by 195 countries, has led to the setting of some ambitious target reductions in greenhouse gas emissions by most developed countries. The over-arching goal of those reduction targets is to limit global warming to less than $2^{o}C$ compared to pre-industrial levels. Yet, despite these commitments from the highest governance levels, there is still no deterministic model on how these national target reductions will be cascaded down to the commercial sector, which accounts for the lion's share of these emissions. In this paper, we present a novel framework which enables the setting, measurement and tracking of the emissions performance of every commercial entity based on a single metric. We further present empirical evidence from the automotive industry to illustrate how the model helps to readily identify the low versus high performers. The model also reveals one car company that stands out as the industry benchmark by already exceeding the performance required by the 2025 emissions target set by the US. The model proves successful in achieving the objectives of being: science-based, goal-driven, equitable, comparable and actionable, and as such can be readily used to accurately compare competitors from the same industry and provide the basis of a more equitable, performance-based carbon tax market, as well as the ability to assess accurately how well a specific country is meeting its reduction quota and how the various industry sectors are impacting that goal.

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1. Introduction

In September 2016, the Scripps Institutions of Oceanography reported that carbon dioxide crossed the significant and symbolic threshold of 400 ppm (parts per million) for the first time in human history. Based on paleoclimatic evidence, the last time CO_2 levels reached 400 ppm humans didn't yet exist. Indeed, a 2009 report from the Nature Geoscience journal found evidence of levels of 365–415 ppm going back to 4.5 million years ago (Pagani et al., 2009). To bring things into perspective, the current levels of 400 ppm are about 120 ppm higher than the pre-industrial levels in the later 1800s, or more than a third higher (Pagani et al., 2009). With three quarters of the world's mega-cities, representing 80% of the world's population, located by the sea (SaveTheSea, 2017), the disastrous consequences of extreme weather events due to the greenhouse effect are simply unfathomable. It is hence difficult to overstate the urgency of reducing greenhouse emissions on a global scale in a way that is predictable and effective. Yet, even after the historic Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC), where aggressive greenhouse gases emission mitigation targets were set (The Paris Agreement, 2016), there is still no clear strategy or game plan for how to reach those aggressive reduction targets. In fact, recent research suggests that the US is on pace to miss its 2025 target in Paris climate deal by a range of 551 to 1800 MMt-CO_2e (million metric tons of CO_2 equivalent), with resulting net changes in GHGE ranging from 0.6% above to 11.8% below the 2005 level (Greenblatt and Wei, 2016); a far cry from the promised 28% reduction even in the best case scenario. Similarly, Environment Canada recently announced that it projects to miss its 2030 GHGE target by about 30% resulting in essentially flat emissions of about 741 MMt-CO_2e, instead of the ambitious goal of 523 MMt-CO_2e promised at the landmark Paris climate summit (ECCA, 2017).

The US framework for GHGE reduction revolves around the Obama Administration's Clean Power Plan, which includes passed and proposed legislation, as well as potential policy or voluntary measures to support the announced reduction target. These wide reaching measures cover electricity and building codes, fertilizer management, appliance standards, heavy-duty vehicles, oil and gas

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CH_4 leaks, manure management and landfills CH_4 emissions (INDC, 2015). Although the US Environmental Protection Agency (EPA) has included carbon pricing, in the form of cap-and-trade, as an option for implementation plans, it has left it up to the individual states to decide to what extent pricing will be used to achieve the Clean Power Plan goals (Lawson, 2016). On the other hand, Environment Canada has made carbon pricing the first and most important pillar of its four-pillar framework to achieve its 30% target reduction of GHGE by 2030 (ECCA, 2017). For both countries however, the unfortunate reality is that it has become exceedingly clear that neither set of policies appear to be enough to reach those self-assigned goals (Greenblatt and Wei, 2016; ECCA, 2017).

Besides the emergence and implementation of detailed government policies to curb GHGE and mitigate climate change, there has been an exponential growth in voluntary reporting in the last fifteen years. Chief among the reporting frameworks is the Global Reporting Initiative (GRI), which has seen its member organizations grow to more than 10,630 organization in 2016 in about 15 years since inception (SDD, 2017). Although sustainability reporting was initially believed to help its members become more sustainable (Initiative, 2014), the general consensus among the literature is that reporting is clearly insufficient in driving meaningful reductions (Fonseca et al., 2012; Ioannou and Serafeim, 2011; Isaksson and Steimle, 2009; Eccles et al., 2014). Higgins and Coffey suggest that while current reporting allows stakeholders to create a dialogue with companies (Higgins and Cofey, 2016), they have recommended substantial changes to the current structure of sustainability reporting. In addition, Isaksson and Steimle firmly state that the GRI guidelines fail to ensure that a report answers the questions of how sustainable a company is or how quickly it is approaching sustainability (Isaksson and Steimle, 2009). Even within the latest G4 framework, individual companies dispose of a great deal of latitude on what and how to report, and how to illustrate it, with varying degrees of opacity and little to no repercussion for failing to perform against emission targets or for that matter any other sustainability metric. A recent paper by Belkhir et al. illustrates how current sustainability practices can actually be very misleading (Belkhir et al., 2017). Using rigorous statistical analysis, they show in particular that there is no significant difference in emissions between companies strictly complying with the highest standards of the GRI and those that don't subscribe to GRI at all. Their findings even suggest that in some cases, the current reporting methods might be rewarding of the least sustainable companies and painting in poor light those that are both succeeding as a business and as a sustainable entity. Indeed, a thriving young company that has developed a low-carbon innovative technology might see its emissions grow extremely rapidly in its growing stage, and hence be severely penalized by undiscriminating carbon pricing. Conversely, a highly emitting company may see its emissions drop not because of any emissions reduction actions, but simply because of loss of market share. Yet, in the eyes of policy measures as they stand today, that company could benefit from the “hype” of emissions reduction.

This state of affairs hence begs the key question: How is setting emissions targets at a country level going to translate into a commensurate target at the firm or entity level in a way that is fair and deterministic? If we are to reach the ambitious goals set by 195 countries in Paris (The Paris Agreement, 2016), we need a measurement and reporting system that is (i) science-based, (ii) goal-driven, (iii) equitable, (iv) comparable and (v) actionable. Only then will we be able to develop a game-plan that will allow us to reach the reduction targets that might spare our world the weather catastrophes that are otherwise certain to happen.

In this paper we outline the theoretical framework that provides for the first time, to our knowledge, a mathematically rigorous method that meets those five above conditions and allows us to measure and manage greenhouse gas emissions (GHGE) from the national level down to the firm or entity level, and closes the loop back to the national set targets. A key contribution of this paper is the demonstration that a standard definition of emission intensities at both the firm and industry sector levels, and the formulation of a relative emission intensity ratio, provides a single standard metric that enables a fair and objective assessment of the performance of both the sector and the individual firms belonging to that sector relative to the target reductions expected from that sector. Departing from the GRI framework, which leaves the emission intensities to be defined at the discretion of the individual entities, we propose in this paper that the only way of cascading emission reduction targets from the national to the firm level, is to define emission intensity relative to the operating revenues generated by that firm, in such a way that the firm is assessed for changes in emissions that are commensurate to the firm's economic contribution. We then proceed to show that once defined that way, this framework allows for proper comparison between competitors within an industry sector, and allows for equitable allocation of emission budgets, as well as a fair approach to encouraging innovators and discouraging “green-washers” and polluters, hence providing a fair and effective path for performance-based policies, including a more sensible carbon-pricing model.

2. Material and methods

2.1. Conceptual development

For the theoretical part of our paper, we have started by assuming that the total GHGE of any given country is well known and measured in metric tonnes of CO_2 equivalent (Mt-CO_2e). We restrict our emissions to Scope 1 and Scope 2 only. Scope 3 emissions were excluded to avoid double-counting. Since we consider in our model direct (scope 1) and indirect emissions (scope 2) from electricity use, and consider the GHGE by end-use sector, effectively attributing the GHGE from electricity production to the sectors that use that electricity. We hence exclude the electricity generation by utilities companies since this would cause double-counting as well.

Our model is strictly concerned with only the commercial sector, and how to cascade the GHGE reduction target from the national level down to the individual firms and entities in a fair and deterministic way, and that takes into account the market dynamics and competitive pressures between the entities of a given industry sector. As such and in its present form, it does not extend to emissions from the public sector, the residential sector or the passenger car sector. Currently, it's estimated by the US Environmental Protection Agency (EPA) that the Scope 1+2 GHGE amount to 33% from Residential & Commercial buildings, 29% from Industry, 27% from Transportation, and 9% from Agriculture (U.S. Environmental Protection Agency, 2017). GHGE from Commercial buildings accounted for about 60% of the Residential & Commercial sector (U.S. Environmental Protection Agency, 2017), while GHGE from commercial transportation accounted for about 40% of the total emissions from the transportation sector (Greene and Plotkin, 2003). Adding all the contributions together, we estimated the total emissions from the commercial sectors to account for 67% of total emissions of all the sectors at the country level, or about 4385 MMt-CO_2e of the total 6587 MMt-CO_2e produced in 2015 in the US (C. C. D. U.S. EPA and OAR, 2017). We show hence that the commercial sectors accounts for the lion's share of the total Scope 1+2 emissions at the country level, in the US. In our model, we will use a multiplier $0 < \eta < 1$, which represents the portion of the GHGE from the commercial sector relative to the total national level.

In our analysis of the emissions from the sector and entity level,

we will use a key metric, namely the emission intensity metric defined as the ratio of Mt-CO_2e to the operating revenues generated by either the entity or the total sector in millions of dollars ($M). This emission intensity ratio defined relative to revenues has been widely used in sustainability and emissions reporting frameworks such as GRI (Global Reporting Initiativr; CDP, 2016), although both the GRI 4.0 and the CDP guidelines allow organizations to use their own organization-specific denominator, which can be profit, EBITDA, units of productions, etc. Other authors have proposed using units of GDP as a common denominator instead of revenues (Randers, 2012). The caveat with allowing companies to use their own denominator is that it undermines the comparability criteria between companies of the same sector, as well as the ability to tie and cascade the emissions reduction target from the sector level to the entity level. Note also that operating revenues are defined as strictly from operations and exclude any changes in revenues through divestiture or acquisitions, investments or other form of one-time transactions that fall outside the day to day operations of the firm. We also argue in this paper that revenue is not only a fair and simple common denominator to use between companies within the same sector, it's also the most appropriate from four separate standpoints: (i) It can be seen as a proxy metric for the economic value-added that a company has contributed to society or the market place, and that the market place has valued to an amount equal to the aggregate revenues. (ii) Similarly, if we use the GHGE as the environmental and social cost to society that the company has imposed on society in exchange for that economic value creation, then the ratio of emission over revenue, becomes an external cost/benefit ratio that is society-centric rather than company-centric. Other internal metrics such as units of production, EBIDTA or other forms of profit fail to capture the external economic value created by the company. (iii) Finally, revenue is a well defined and readily available number that every company already tracks and documents according to global standards. Other proposed denominators such as GDP for example (Randers, 2012) are much harder to measure and hence much harder to standardize. (iv) We argue in this paper that the simplest form of cutting emissions, which is the proportional cuts method, is not fair. For example asking every company to cut 30% of their emissions by 2030, or 2.14% per year, would unfairly penalize the fast growing companies who may be greener and more innovative than their competitors, but growing faster *because* of their innovative technologies. At the same time, companies who may be meeting those reduction targets because of their shrinking revenues may be viewed in a more favorable light, while in fact their emission intensity levels may be much higher than their growing competitors. In our data analysis section, we will show an example that precisely illustrates this case.

2.2. Data capture and analysis

To illustrate the theoretical model, we used the ET Carbon Dataset from ET Index Research, which produces a public Carbon Ranking of the world's largest listed companies and access to 2000 companies, analyzed directly by ET Index Research as well as modelled data available for all companies in Bloomberg, and which includes SICS mapping (Index, 2017). Among other data, the dataset provides the Scope 1 and 2 of the automotive sector from 2008 to 2016, as well the emissions intensity in Mt-CO_2e/$M (USD). We restricted our analysis to the automotive sector in this paper for illustrative purposes of our model.

2.3. Data availability

The data that support the findings of this study are available from ET Index Research but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available.

3. Theoretical framework

This section lays the mathematical foundation of our proposed framework for measurement and reporting of emissions at the national, industry sector, and entity levels. Let $E(n)$ represent the carbon budget in the *nth* year and $\Delta(n)$ be the reduction in emissions that is necessary over n years to reach that goal. Also, let η, represent the portion of $E(n)$ produced by the integrality of all the commercial sectors combined. Then for all of the j entities within each of the i sectors, which we shall assume here to remain constant over the horizon of time under consideration, we have

$$\sum_i E_i(n) = \eta E(n), \qquad \sum_j E_{i,j}(n) = E_i(n). \tag{1}$$

Also, assuming the sum total of the target reductions by the commercial sector is proportional to its contribution, we also have

$$\sum_i \Delta_i(n) = \eta \Delta(n), \tag{2}$$

For a market growth rate of d_i of a sector i and growth rate of $d_{i,j}$ of an entity j within that sector, we can write the total market size of that sector R_i and the revenue at the entity level $R_{i,j}$ as,

$$\begin{aligned} R_i(n) &= R_i(0) \cdot \textstyle\prod_{m=1}^{n} (1 + d_i(m)), \\ R_{i,j}(n) &= R_{i,j}(0) \cdot \textstyle\prod_{m=1}^{n} (1 + d_{i,j}(m)), \end{aligned} \tag{3}$$

$$I_i(n) = \frac{E_i(n)}{R_i(n)}, \qquad I_{i,j}(n) = \frac{E_{i,j}(n)}{R_{i,j}(n)}, \tag{4}$$

where I is the emissions intensity ratio. In theory, if the goals that we set are to be reached, an entity share of its sector's emissions should be equal or less than its market share within that same sector. Let $r_{i,j}$ and $e_{i,j}$ represent an entity j's market share and emissions share in sector i,

$$\begin{aligned} r_{i,j}(n) &= \frac{R_{i,j}(n)}{R_i(n)} = \frac{R_{i,j}(0)}{R_i(0)} \cdot \prod_{m=1}^{n} \left(\frac{1 + d_{i,j}(m)}{1 + d_i(m)} \right), \\ e_{i,j}(n) &= \frac{E_{i,j}(n)}{E_i(n)}. \end{aligned} \tag{5}$$

Next we define the target emissions intensity at the sector level:

$$I_i^t(n) = \frac{E_i^t(n)}{R_i(n)} = \frac{E_i(0) - \Delta_i^t(n)}{R_i(0) \cdot \prod_{m=1}^{n} (1 + d_i(m))} \tag{6}$$

Based on the above, we now introduce the *Sustainability Ratio* $RI_{i,j}$, where each entity should aim for less than or equal to 1 to meet its fair share of target reduction.

$$RI_{i,j} = \frac{e_{i,j}}{r_{i,j}} = \frac{I_{i,j}}{I_i^t} \quad \leq \quad 1. \tag{7}$$

For Eq. (7) to hold true, the minimum target emissions intensity, in any given year m, for an entity j belonging to a sector i is,

$$I_{i,j}(n) = I_i^t(n), \tag{8}$$

where $I_i^t(n)$, is the *projected* target emissions intensity of the sector i at any given year $0 < n < N$ and given by the following expression:

$$I_i^t(n) = \frac{E_i(0)}{R_i(0)} \cdot \frac{(1-\delta)^{n/N}}{(1+\ d_i)^n} = I_i(0)\exp[n\ln(1-\delta)/N - n\ln(1+\ d_i)], \quad (9)$$

where $\delta = \Delta_i(N)/E_i(0)$, the relative target reduction by year N, and d_i is the average expected growth of the sector i with the time horizon under consideration, i.e. between 0 and N years.

It follows that the entity's required emission intensity and total absolute emissions, respectively, necessary to meet their own target are,

$$I_{i,j}(n) \leq \begin{cases} I_i^t(n), & \text{on a projected basis} \\ \dfrac{E_i(0) - \Delta_i^t(n)}{R_i(0) \cdot \prod_{m=1}^{n}(1+\ d_i(m))} & \text{on an actual basis} \end{cases} \quad (10)$$

$$E_{i,j}(n) \leq r_{i,j}(0) \cdot \left(E_i(0) - \Delta_i^t(n)\right) \cdot \prod_{m=1}^{n}\left(\frac{1+\ d_{i,j}(m)}{1+\ d_i(m)}\right), \quad (11)$$

Eqs. (10) and (11) are the main results of this paper. The input values therein are all known, and the equations are the actionable results of this framework that an entity can use to aim for its own as well its nation's targets. In Eq. (10), the *projected basis* version of the equation is used to set a numerical target for the firm based on the projected target emission intensity for the sector, given by Eq. (9). Once the actual growth of the sector i is known for the year n, then the *actual basis* version is to be used to compare with the actual emission intensity achieved by the firm j for that same year.

In order to close the loop and show that the sum total of all the entities' reductions amounts to the total national reduction, we sum over i and j the emissions of all the entities in year n as expressed in Eq. (11) above to show that it adds up to the total national emissions in year n as demonstrated by Eq. (13) below.

$$\begin{aligned} \sum_{i,j} E_{i,j}(n) &= \sum_{i,j} r_{i,j}(0) \cdot (E_i(0) - \Delta_i(n)) \cdot \prod_{m=1}^{n}\left(\frac{1+\ d_{i,j}(m)}{1+\ d_i(m)}\right) \\ &= \sum_i \frac{E_i(0) - \Delta_i(n)}{\prod_{m=1}^{n}(1+\ d_i(m))} \sum_j r_{i,j}(0) \cdot \prod_{m=1}^{n}(1+\ d_{i,j}(m)) \end{aligned} \quad (12)$$

where the sum over j is equal to $1 \cdot \prod_{m=1}^{n}(1+\ d_i(m))$ since the sum total of all entities' growth relative to their market share is equal to the total growth of sector i, leading to the cancellation of the denominator, and leaving

$$\sum_i E_i(0) - \Delta_i(n) = \eta E(0) - \eta\Delta(n) = \eta E(n). \quad (13)$$

which brings us back to our original eq. (1).

3.1. Impact of market dynamics

A major gap in voluntary corporate reporting methods, e.g. GRI, as well as in policies that seek a proportional carbon pricing, is that they both ignore the change in relative market share of a given entity within its sector and the overall growth of that sector as described in Eq. (5) and (3), hence completely neglecting the dynamic nature of business and markets. Without incorporating the growth (or decline) of industries and the within sector competitive pressures and dynamics, companies that increase their emissions intensity above their sector's intensity, yet see their absolute emissions decreasing due to decreased revenues or loss of market share tend to be viewed favorably, while companies that are rapidly gaining market share and hence seeing their total emissions growing, despite an emissions intensity that is lower than their sector's ($RI_{i,j} < 1$) are frowned upon as "polluters" when in fact they should be encouraged and rewarded. For instance, Eq. (11) shows that $E_{i,j}(n)$ could be higher than $E_{i,j}(0)$ resulting in an increase in emissions because of a company growth that is much higher than its industry's, yet, that company is still meeting or exceeding the sustainability condition and the reduction targets of the overall sector. Conversely, a company that might have reduced its emissions by more than the proportional amount required from the whole sector but did so by losing a proportionally higher amount of market share would not meet the sustainability condition and hence is not contributing its fair share to the reduction target of the whole sector. This non-intuitive but mathematically rigorous result will be illustrated with empirical evidence found in the automotive sector in the sections below.

In Fig. 1, using the US as an example, we show a graphical representation of the cascading of the emissions reduction target from the national down to the commercial entity level for every year n as described in the theoretical framework presented above. The national reduction targets can be broken down into sectors, and entities within sectors. The emissions intensity metric can be used to compare entities within a sector, allowing them to reach their targets. An entity with a relative intensity of greater than 1 is poorly performing while an entity with an $RI_{i,j} \leq 1$ has reached or is outperforming the emissions targets. For the sake of simplicity of illustration, we have assumed here that the growth rates for the sector and the entity are constant year over year.

4. Results

In order to illustrate the theoretical framework discussed in this paper, we examined the auto industry over a two-year period from 2014 to 2015. There were ten major auto companies that reported scope 1 and scope 2 CO_2 in those two years. Fig. 2 shows the change in emissions for those ten auto companies. At first blush, GM and Yamaha appear to lead with 10% reduction in emissions, followed by Nissan and Daimler with reductions of almost 5% and Ford with a reduction of 2.5%. On the other hand, the figure shows that Mazda's emissions increased by 18% followed afar by BMW and KIA with increases of 3% and 2% respectively, and marginal increases by Honda and Renault.

This picture however changes dramatically when plotting the normalized emission intensity ratios of these same companies in 2015, as shown in Fig. 3. There we see that GM that had the highest reduction in emission is in fact the worst performer with a normalized intensity of 0.6, i.e. having an emission intensity that is 60% *higher* than its industry sector, followed by Honda and Yahama; the latter also showing the second largest reduction in emissions in Fig. 2. As for the best performers, we discover that BMW is by far the best performer in 2015, despite its increase in emissions of 3%, with a relative emission intensity that is 54% lower than its industry sector, followed by Daimler, Renault, Kia and Mazda.

To explain this result, it's worth noting that in 2015 GM and Yamaha incurred a decline in their revenues of about 2% and 6% respectively. Their reduction of 10% each in total emissions is only partially explained by their decrease in revenues. The balance of their reduction is accounted for by a net reduction in their emissions intensity which decreased from 54.1 to 49.5 Mt-CO_2e/$M (9%) for GM and from 43.4 to 41.7 Mt-CO_2e/$M (4%) for Yamaha, hence

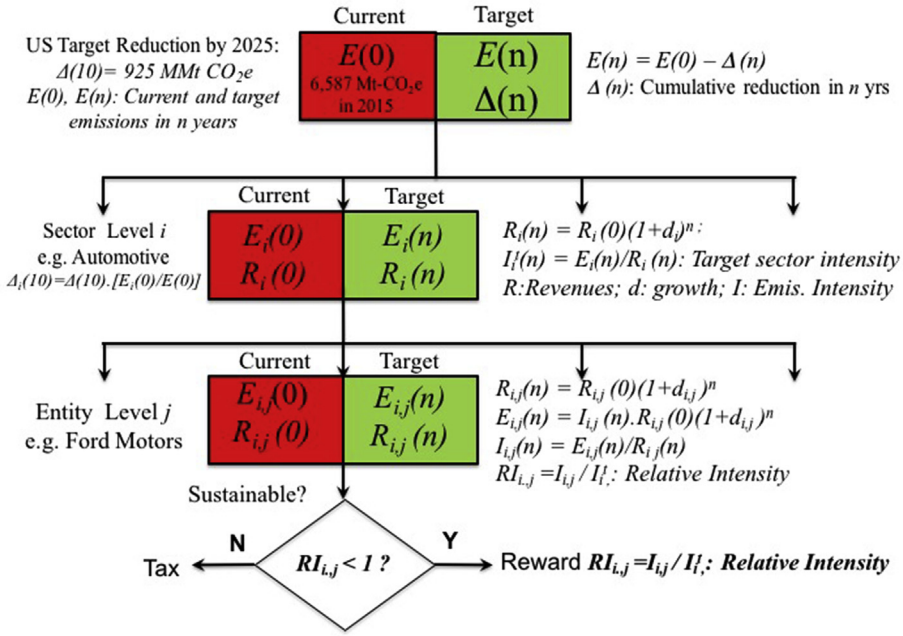

Fig. 1. Flow diagram showing the cascading year-over-year of the national-level target reduction down to the commercial entity level, and the sustainability condition to test whether a given entity has met its fair share of reductions relative to the target reductions.

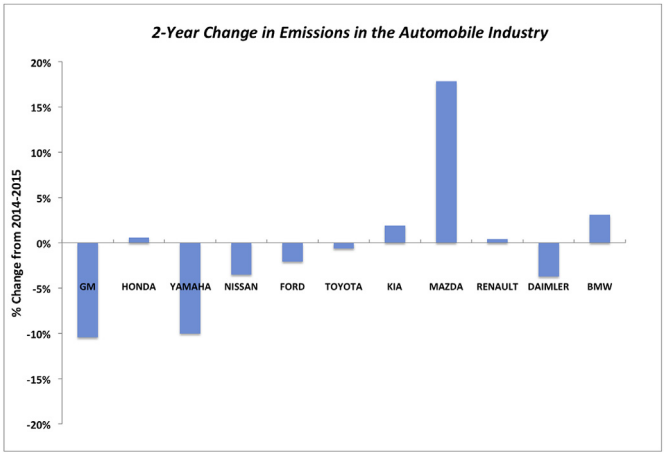

Fig. 2. Change in CO_2 emissions by the big auto makers from 2014 to 2015. Source: ET Index Research.

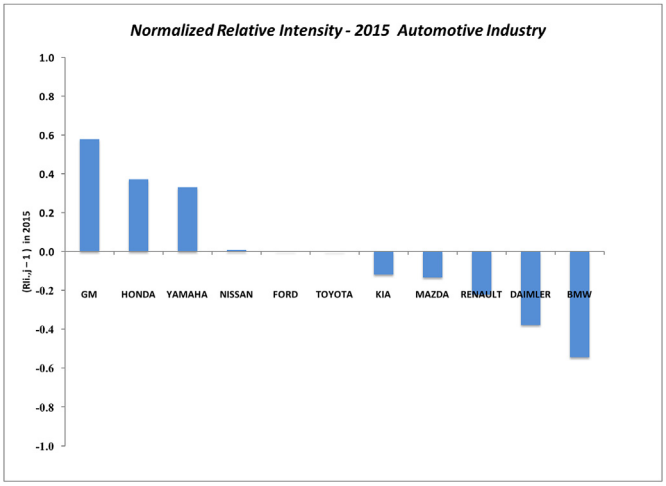

Fig. 3. Normalized relative emission intensities for the top 10 car makers. Below zero are companies that are better than their sector and above zero are worse.

accounting in full for their change in emissions. However, for both companies, their emissions intensities (49.5 and 41.7 for GM and Yamaha respectively) still compare very unfavorably with the emissions intensity of 31.37 for the overall automotive sector.

On the other hand, BMW revenues in 2015 increased by 2% in 2015 from $100 to $102 billion, while their emissions increased by only 3%. The remaining 1% was caused by a slight increase in their emissions intensity from 14.15 to 14.3 Mt-CO_2e/$M, which is still less than 1/3 that of GM. We should note here that in the case of BMW, their revenues increase in 2015 in euros grew 14.6%, from €80.4 in 2014 to €92.2 billion. The more than 10% appreciation of the US$ suppressed that growth to only 2% when measured in USD.

In Fig. 4 we plot the target emissions intensity for the automotive sector, as given by Eq. (9), that is required in order to achieve the 28% emissions reduction target by 2025 (relative to 2005 levels) promised by the US at the Paris Summit (INDC, 2015). Taking into account the 11.5% reductions achieved from 2005 to 2015, the annual reductions in emissions required amount to $\delta = 1.9\%$ per year. Also, for the sake of illustration, we assumed a realistic average annual global growth of $d_i = 3\%$ in the automotive sector from 2015 to 2025 (Alix Partners, 2015). Accordingly, we show that by 2025, the emissions intensity of the whole automotive sector should drop from its current 31.37 Mt-CO_2e/$M to 19.26 Mt-$CO_2$e/$M, or a total 39% reduction from current levels. Should the sector growth be greater than 3%, then the reductions required would be even greater.

In Fig. 5, we show the 2015 emissions intensity of the 10 auto makers plotted against the projected auto sector overall emissions intensity in 2015, 2020 and 2025 required for the sector to meet the 2025 US GHGE reductions target. This allows us to immediately identify how well each company fares not only against the current sector level, but also against future sector levels. We observe that 3 out of the 10 are already exceeding their 2015 sector emissions

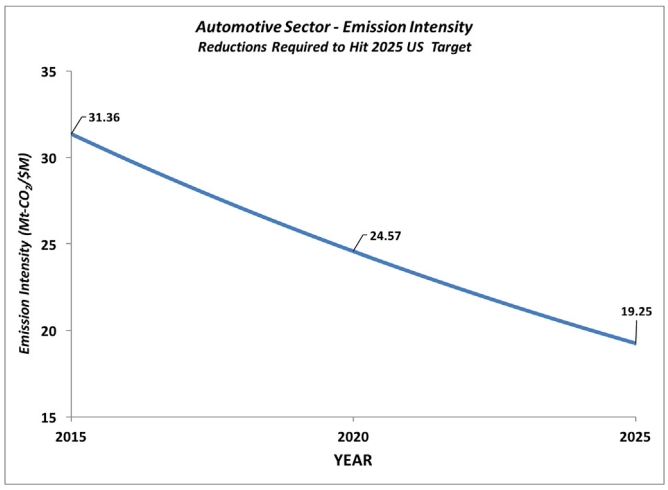

Fig. 4. Projection of the emission intensity of the automotive sector that is required to meet the US GHGE reduction target of 28% reduction in 2025 compared to 2005 levels.

intensity, while only 3 car companies meet the 2020 required intensity level, and only 1 company, namely BMW, which with an intensity level of 14.3 Mt-CO_2e/$M already easily meets the sector intensity level of 19.26 targeted for 2025. A remarkable result of this approach is that it enables the easy identification of the sector leader that can serve as a benchmark for the rest of the sector players. Also, it provides evidence that the dramatic cuts in emissions that BMW has been able to achieve did not undermine its financial performance, quite the contrary in fact.

It is instructive to look at the change over time in the emissions intensities of the automotive companies analyzed above as a reflection of their efforts to reduce their environmental efficiency. Fig. 6 shows the emissions intensity for 7 of the 10 companies analyzed above for the years 2010, 2012, 2014, and 2015. The data was only available for BMW, Daimler, Renault, Kia, Ford, Honda and GM. We observe that BMW still leads by a significant gap with an emissions intensity level that is consistently and markedly lower than all its peers. In addition, we observe that Daimler has made significant and sustained strides in reducing its emissions intensity from 28.3 in 2010 down to 19.5; a full 31% reduction in 5 years. Also, Ford shows significant and sustained reduction of its emission from a high of 41.1 in 2010 to a low of 31.4 in 2015, amounting to an overall reduction of 23% and in line with the overall sector emissions intensity of 31.37 in 2015. On the other hand, Renault, Kia and Honda do not show any visible trend in their emission intensities, with both showing a dip in 2012 and then a significant increase in 2014 and 2015. Finally GM appears here to be by far and consistently the worst performer overall, even if it is laudable for its apparent downtrend in emission intensity, resulting in about 15% reduction from 2010 to 2015. On the other hand, and in sharp contrast with all its corporate posturing about its sustainability initiatives, Honda is not only the second worst performer of its sector, but also appears to be on upward trend showing a 34% increase from 2010 to 2014 which then drops in 2015, but still maintaining a net increase of 10% from 2010 to 2015. Presented in this format, the absolute as well as the relative performances of each company become totally transparent and unequivocal, and lend themselves to further analysis as well as concrete actions and initiatives, both from a corporate management as well as from a public policy perspective.

Finally, to complete the illustration of our proposed theoretical model, and in particular how individual companies can use Eq. (10) to determine their maximum allowable emissions year over year. Although Eq. (10) as written takes as input the actual yearly growth in the firm's market share and the overall sector, one can still assume, for projections purposes, expected growth rates for their particular firm. For the purpose of our illustration, we assume that all the firms' growth rate is equal to their overall sector, i.e. constant market share. This further simplifies Eq. (10), and reduces it to:

$$E_{i,j}(n) \leq r_{i,j}(0) \cdot \left(E_i(0) - \Delta_i^t(n)\right), \tag{14}$$

Applying this equation to the automotive sector, we can easily now calculate the maximum allowable emissions for each company between 2015 and 2025 as shown in Fig. 7. We observe that the sector is split into three (The Paris Agreement, 2016) categories of firms; (i) ones that need to reduce their emissions drastically in

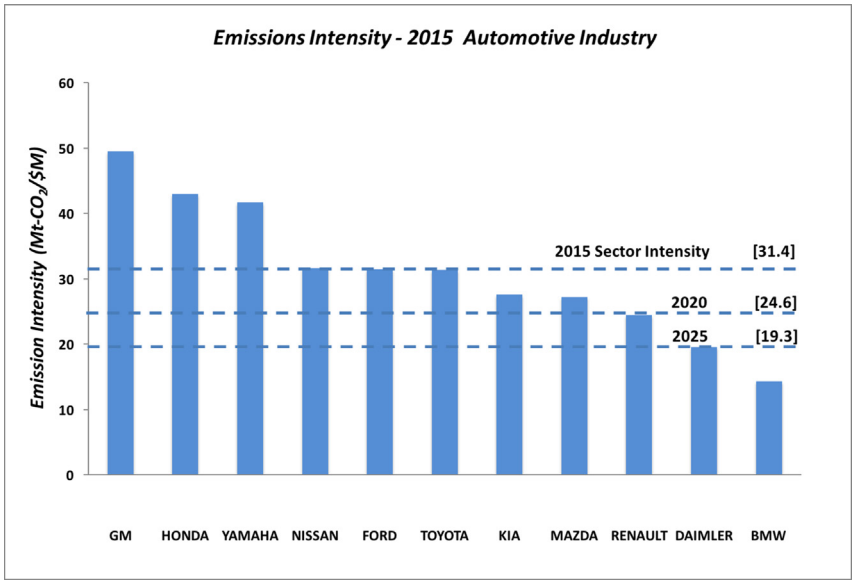

Fig. 5. Emission intensities for the 10 big auto makers in 2015, shown with the emission intensity of the automotive sector in 2015, along with the projected levels in 2020 and 2025 that need to be achieved by the sector as a whole in order to achieve the US target reductions of 25% by 2025 compared to 2005 levels. (Source: ET Index Research.)

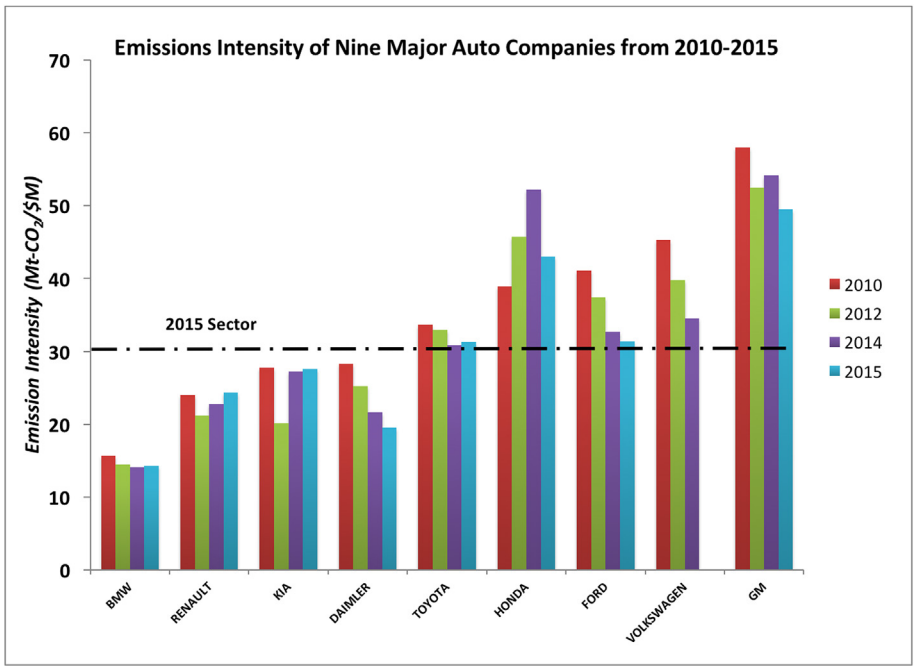

Fig. 6. Historical emissions intensities for 6 automotive companies for the years of 2010, 2012, 2014, and 2015. (Source: ET Index Research. The GM 2010 and 2012 data was not available from ET Index and was instead obtained from GM's sustainability and financial reports on GM's website).

order to meet their fair share, and those include Toyota, GM, Honda, Ford and Nissan in order of descending levels of current emissions; (ii) companies that are already performing below their current emissions target and hence have a fairly flat allowable emissions levels, such as Renault, Kia, Mazda and Yamaha, and finally (iii) companies that are already or almost meeting their future 2025 emissions target and hence have an increasing allowable level between the present to 2025. Only two companies fall into that category and those are BMW and Daimler. It's important to note that the "allowable level" is not the "target level", but rather the maximum emissions level that a company has to perform below in order to avoid exceeding its fair share of emissions. This is the level of emissions that policy makers could use to trigger potential penalties and carbon taxes.

Let us now discuss some of the limitations of our model, from both a conceptual as well as a practical perspective. Conceptually, the model assumes a constant proportion of the emissions of the commercial sector relative to the total emissions of the country, i.e. $\eta = constant$ (see Eq. (1)). This assumption is however a simplification of the reality, as η can fluctuate year over year. A generalization of the model to include a variable η while outside the scope of this paper should be fairly straightforward. That said, the fluctuations of η have no effect on either the setting of the emission intensity target at the sector level or the actual firm ranking within their sector. Another conceptual limitation is that the model, as it stands, does not address the non-commercial sector and is limited to where the intensity metric is defined exclusively relative to sales. An extension of the model to non-commercial entities with appropriately defined intensity metrics would be a valuable research direction.

From a practical viewpoint, and in order to be effective, all companies in a given sector have to agree to report their scope 1 and scope 2 emissions as well as their annual global sales in a readily accessible, transparent and regular manner. While such data is currently publicly available, it is not conveniently accessible in its raw form, let alone in a format that lends itself to quick and reliable interpretation. Finally, a more serious limitation of our model is the fact that multinational firms, such as the automotive companies, operating in many countries, where each country has a different reduction target, may be subjected to significantly different levels of reduction targets. While the model, as it stands, lends itself to country-specific target setting, it is probably not easily feasible for companies to comply with several country-specific emissions reductions, and hence may have to deal with different emission targets. One possible way out would be for companies to strive to achieve the most aggressive emissions target of any country in which they have a significant presence. Another, perhaps more realistic way, would be to adopt the adopt the target of the country or region where they?re headquartered, such the US for GM and Ford, and Japan for Toyota and Honda, and the E.U. for Daimler and BMW. Regardless of the target they chose, and of whether they're multinationals or not, the model remains fully viable in providing

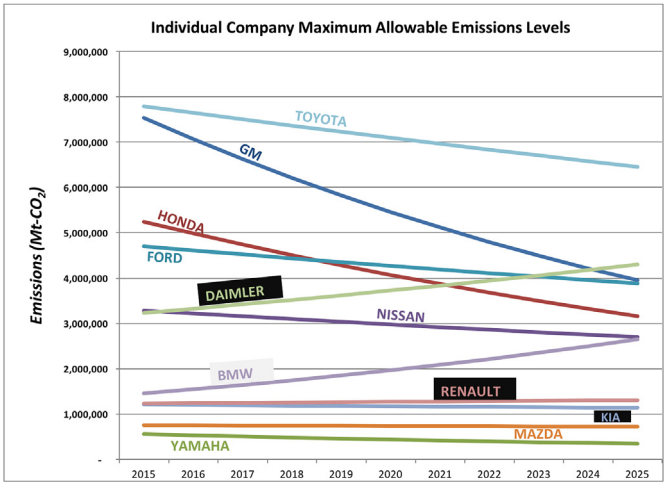

Fig. 7. Projection of the emission intensity of the automotive sector that is required to meet the US GHGE reduction target of 28% reduction in 2025 compared to 2005 levels.

an objective and comparable ranking of all the companies that belong to the same sector.

5. Discussion

In the first part of our empirical analysis, we have shown how the application of our theoretical model to the automotive industry using real data demonstrates how a single quantitative metric, namely the relative emission intensity, defined as the ratio of the emission intensity of the firm over the overall sector emission intensity, can be used not only to assess unequivocally the firm's performance relative to its peers, but also, and perhaps more importantly, to assess the performance of that firm against the national reductions targets of the country in which the firm operates. In the case of the automotive industry, and as an additional bonus, the model uncovered a single company, namely BMW, that was leading its sector by far, and performing already at the US-based 2025 emissions reduction level. This provides an important proof and case in point of the reasonableness of those targets as well as a benchmark that other firms from the same sector can learn from. Taken all together, the relative emission intensity metric can be effectively used for ranking the individual entities in terms of their emissions performance, taking into account their individual financial performance, as well as that of their overall sector, in an equitable and transparent manner.

In the second part of our analysis, we have used the year-over-year (yoy) intensity metric of each of the ten (Fonseca et al., 2012) largest automotive companies to analyze their historical trends and hence get a better perspective of their long-term direction and commitment towards a more sustainable performance. We have found that while some, like Daimler, Ford, Volkswagen and GM, appear to exhibit a consistent and encouraging downtrend in their emission intensities, others such as Renault, Kia, and Honda show no such downtrend. This analysis could prove valuable not only to policy makers for the purpose of developing fair and effective carbon pricing and taxation policies, but also to corporate leaders who seek to evaluate whether their emissions reductions strategies are bearing fruit or need further re-adjustments.

Finally, we have shown at the end of our analysis how the model can be used by the individual firms to project out their maximum allowable emissions based on their country's reduction targets, their sector economic growth, as well as their own growth. It may come somewhat counter-intuitively to the reader that those allowable emissions may actually increase for certain companies, such as BMW and Daimler, when the overall sector emissions have to decrease year over year. We have explained in our results section how the allowable emissions are not the same as target emissions, but rather the maximum emissions a company can afford without exceeding its fair share of emissions, defined a relative emission intensity of 1 for that particular year. Hence, a company such as BMW or Daimler that have a relative emission intensity much smaller than 1 would be allowed to have a higher level of emissions before facing any punitive carbon pricing or taxation measures. That is not to say however that companies who perform in that regime should be encouraged or even expected to increase their emissions.

6. Conclusion

In conclusion, we have proposed a novel science-based, goal-driven, equitable, comparable and actionable framework for measuring and reporting emissions that enables the cascading of GHGE target reduction from the national level down to the firm level, capturing accurately the market dynamics and competitive pressures within an industry, and allowing a year-over-year performance tracking against targets at the industry sector and firm levels. A key contribution of our model is the introduction of a single metric, namely the *relative emissions intensity* metric with revenues as the standardized common denominator, that allows for the immediate differentiation between the over-performers from the under-performers relative to their sector target emissions.

Using real data from the automotive industry, we illustrated the potency of the framework by showing how it provides an unequivocal and robust ranking of the individual car companies relative to their sector, helping identify the sector's leader as well as evaluating the current performance of those firms against current and future performance targets.

We believe that our framework can be used to enable the formulation and deployment of more equitable and effective policies, such as carbon pricing, that will be deployed in a targeted and performance-based manner rather than across the board and undiscriminating. Standardized voluntary reporting in such a way that every entity's emissions intensity uses the entities' revenue as their denominator would be required to facilitate comparability and accountability. Furthermore, the ability to identify a benchmark that is already meeting or even exceeding its fair share of the GHGE reductions could be used as a powerful incentive for the other industry players to learn and transfer its best practices in a way that is reminiscent of the Quality Movement in the 70's and 80's, when the US companies were seriously challenged by the Japanese companies with better and lower cost products.

Finally, we point out that this framework can be straightforwardly extended to other key sustainability metrics, including but not limited to water consumption and waste reductions.

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References

Alix Partners, 2015. The Worldwide Automotive Growth Is Slowing Down. Last Accessed 21 August 2017. http://legacy.alixpartners.com/en/MediaCenter/PressReleases/tabid/821/articleType/ArticleView/articleId/1690/The-Worldwide-Automotive-Growth-Is-Slowing-Down-Particularly-in-the-BRICS-At-the-Same-Time-the-Industry-Face-Huge-Technological-Challenges-CASE.aspx#sthash.rxkfupUj.dpbs.

Belkhir, L., Bernard, S., Abdelgadir, S., 2017. Does GRI reporting impact environmental sustainability? a cross-industry analysis of CO_2 emissions performance between GRI-reporting and non-reporting companies. Manag. Environ. Qual. Int. J. 28 (2), 1–18. http://dx.doi.org/10.1108/MEQ-10-2015-0191.

C. C. D. U.S. EPA, OAR, 2017. Inventory of u.s. Greenhouse Gas Emissions and Sinks: 1990-2015. Last Accessed 7 March 2017. https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf.

CDP, 2016. Guidance for Companies Reporting on Climate Change on Behalf of Investors & Supply Chain Members 2016, Carbon Disclosure Project. Last Accessed 14 May 2017. https://www.cdp.net/Documents/Guidance/2016/CDP-2016-Climate-Change-Reporting-Guidance.pdf.

ECCA, 2017. On Clean Growth and Climate Change - Canada's Plan to Address Climate Change and Grow the Economy Mitigation Policies of the United States. Last Accessed 10 March 2017. https://www.canada.ca/content/dam/themes/environment/documents/weather1/20170125–en.pdf.

Eccles, G., Ioannou, I., Serafeim, G., 2014. The impact of corporate sustainability on organizational processes and performance. Manag. Sci. 60 (11), 2835–2857. https://doi.org/10.1287/mnsc.2014.1984.

Fonseca, A., McAllister, M., Fitzpatrick, L., 2012. Sustainability reporting among mining corporations: a constructive critique of the GRI approach. J. Clean. Prod. 1–14. https://doi.org/10.1016/j.jclepro.2012.11.050.

Global Reporting Initiativr, GRI G4 Guidelines and ISO 26000: 2010 How to Use the GRI G4 Guidelines and ISO 26000 in Conjunction, Last Accessed 21 March 2017. https://www.globalreporting.org/resourcelibrary/How-To-Use-the-GRI-Guidelines-In-Conjunction-With-ISO26000.pdf.

Greenblatt, J., Wei, M., 2016. Assessment of the climate commitments and

additional mitigation policies of the United States. Nat. Clim. Change 6 (12), 1090–1093. https://dx.doi.org/10.1038/NCLIMATE3125.
Greene, D.L., Plotkin, S., 2003. Reducing Greenhouse Gas Emission from U.S. Transportation. Pew Center on Global Climate Change, Arlington. http://www.pewclimate.org/docUploads/ustransp.pdf.
Higgins, C., Cofey, B., 2016. Improving how sustainability reports drive change: a critical discourse analysis. J. Clean. Prod. 136, 18–29. https://doi.org/10.1016/j.jclepro.2016.01.101.
INDC, 2015. United States of America U.S. Cover Note, INDC, and Accompanying Information. Last Accessed 2 April 2017 www4.unfccc.int/submissions/INDC/Published_Documents/United_States_of_America/1/U.S.Cover_Note_INDC_and_Accompanying Information.pdf?.
Index, E., 2017. Et Index Research. Last Accessed March 1 2017. https://www.etindex.com/.
Initiative, G.R., 2014. Starting Points? GRI Sustainability Reporting: How Valuable Is the Journey? Last Accessed 6 May 2017. http://database.globalreporting.org/.
Ioannou, I., Serafeim, G., 2011. Executive summary: the power of transparency. Bus. Strategy Rev. 3, 76. https://dx.doi.org/10.1111/j.1467-8616.2011.00780.x.
Isaksson, R., Steimle, U., 2009. What does GRI-reporting tell us about corporate sustainability? Total Qual. Manag. 21 (2), 168–181. https://doi.org/10.1108/17542730910938155.
Lawson, A., 2016 July. Carbon trading under the clean power plan. Mag. Environ. Manag. 66 (7). http://awma-web.s3.amazonaws.com/files/rVn0ploRTDekSgEkZhdT_01-7701_July_EM_Web_Flipbook-Final.pdf.
Pagani, M., Liu, Z., LaRiviere, J., Ravelo, A., 2009. High earth-system climate sensitivity determined from pliocene carbon dioxide concentrations. Nat. Geosci. 3, 27–30. http://dx.doi.org/10.1038/ngeo724.
Randers, J., 2012. Greenhouse gas emissions per unit of value added (GEVA)? a corporate guide to voluntary climate action. Energy Policy 48, 46–55. https://doi.org/10.1016/j.enpol.2012.04.041.
SaveTheSea, 2017. Interesting Ocean Facts. Last Accessed 17 March 2017. http://savethesea.org/.
SDD, 2017. GRI Sustainable Disclosure Database. Last Accessed 25 March 2017. http://database.globalreporting.org/.
The Paris Agreement, 2016. United Nations Framework Convention on Climate Change. Last Accessed 13 July 2017. http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.
U.S. Environmental Protection Agency, 2017. Sources of Greenhouse Gas Emissions. Last Accessed 15 April 2017. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.